4.Zero waste

Vertical extensions: technical challenges and carbon impact

Jenny Pattison discusses the typical considerations that structural engineers face when seeking to add floors to an existing building, and the sustainability outcomes of potential solutions.

Introduction

Vertical extensions to existing buildings are often proposed to maximise the potential for refurbishment on a particular site. They also allow any spare capacity within our existing building stock to be fully utilised, which is crucial to achieve the industry's goal of net-zero carbon. However, there are particular structural challenges associated with vertical extensions that may not be fully appreciated at the outset. This article highlights the technical challenges that may arise so that all scenarios can be considered throughout the development of the design. These are demonstrated with a hypothetical case study – while this is based on the existing building stock and requirements in the UK, the general considerations are applicable elsewhere.

Opportunities

This article is a result of recent work by Arup, predominantly associated with proposed vertical extensions to purpose-built blocks of flats constructed in the UK in the 1960s. Low- to medium-rise buildings are increasingly the target for vertical extensions to provide new homes in the right locations. In England, the government has incentivised these developments through the introduction of new permitted development rights for residential extensions of up to two storeys.

Vertical extensions to existing buildings can provide sustainable outcomes related to material consumption, but can also deliver on other sustainable outcomes. The benefits have been described by others before, with particular reference to rooftop developments in London[1], and are illustrated here with reference to the UN Sustainable Development Goals[2]:

- Responsible consumption through reuse of buildings can reduce carbon emissions and has a direct impact on the climate emergency (Goals 12 and 13).
- Extensions can provide revenue to maintain and upgrade the existing building such as improving energy performance (Goals 7 and 10).
- Increasing the density of housing in urban areas avoids developments on greenfield sites and can reduce the demand on infrastructure, leading to more sustainable cities and communities (Goal 11).

The opportunities for sustainable outcomes must be assessed on a project-by-project basis, but this demonstrates the need for structural engineers to find innovative solutions that can overcome the technical challenges of vertical extensions.

Typical considerations

Demand increase

The target often adopted for reuse or refurbishment of existing buildings is no net increase in the original design loading, which avoids detailed assessment of the capacity and condition of the existing structure and foundations. A justification for lower loading on existing floors can often be made for commercial buildings where generous live load allowances have historically been used, but this is less likely to be possible for residential buildings.

Some benefit may come from removal of existing roof finishes, but this is unlikely to offset the weight of additional storeys. There will also be an increase in wind loading from the increased height which will be more significant for shorter buildings. A vertical extension is therefore expected to increase the demand, which means a structural appraisal will be required to modern codes.

Wind loading

Assessing the increase in wind loading due to additional storeys is an obvious requirement for vertical extensions, but it may also be necessary to consider the change in requirements in modern codes. Within the UK, a wind map was first provided in 1970[3]; prior to that, treatment of wind loads depended on the knowledge and experience of the designer. The calculation of wind pressures has been revised several times since, and while this can be problematic for taller buildings, the changes are rarely an issue for buildings of up to five storeys.

However, some structures from this period lack a designed stability system in one direction since minimal calculations were required for

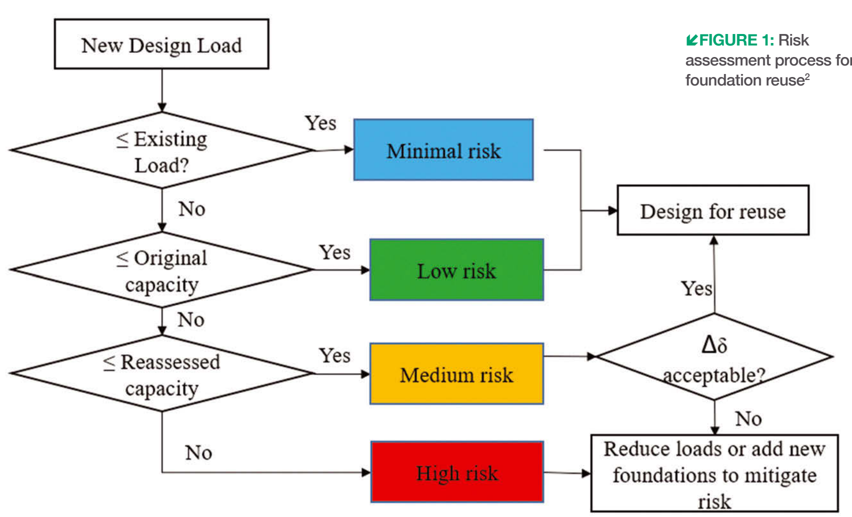

FIGURE 1: Risk assessment process for foundation reuse[2]

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buildings with loadbearing walls. Care must therefore be taken to avoid weakening unintended load paths that may be relied upon for stability. For these reasons, it can often be difficult to justify the wind loads on the extended structure, including pressures, load paths and factors of safety against overturning.

Foundation reuse

The existing foundations will need to be justified for a longer design life and their capacity assessed for any significant increase in demand. The assessment process has been discussed in a recent article in *The Structural Engineer* and is summarised in **Figure 1**[4]. Some trial pits are likely to be required to confirm the condition of the foundations – the extent of the investigations will depend on the capacity required.

Structural appraisal

A structural appraisal will be required for all elements of the existing structure which provide a load path for the extension. An increase in demand is likely for a vertical extension, so the strength and serviceability should be reassessed for all elements within the vertical and stability system. A thorough desk study should be undertaken to understand the original design[5], but drawings and calculations are often not available.

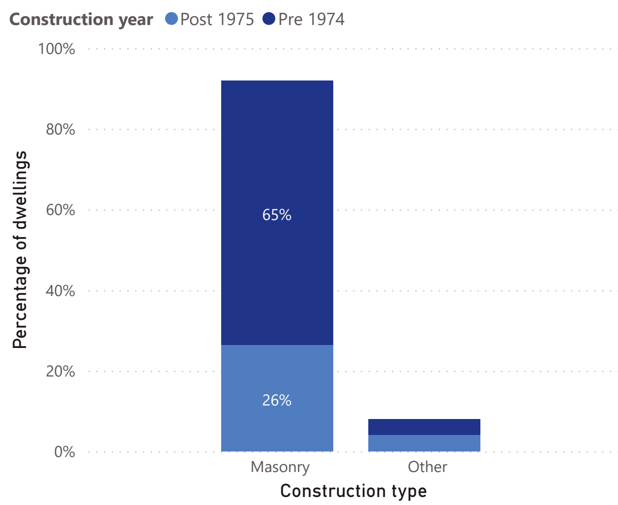
Understanding the codes of practice used at the time of construction is important[6]. Even for more recent structures, such as those built in the 1960s, there are known shortcomings with respect to shear design, robustness, fire resistance and wind loading[7]. Special attention must therefore be paid to these issues within the structural appraisal of the existing building.

Intrusive investigations

Justifying the life extension of the existing structure requires an appraisal of its condition through inspections and surveys. Justifying an increase in capacity will require intrusive investigations to confirm the as-built construction and material properties. This can involve deep trial pits to investigate foundations, local breaking-out of concrete to confirm reinforcement, and taking samples to investigate the materials. This will be disruptive to existing occupants so is often undertaken late in the design process. It is therefore essential that structural risks are identified early and contingencies included if possible.

Robustness

Perhaps the most challenging issue for the structural engineer will be justifying



↑FIGURE 2: Construction and age of purpose-built low-rise flats in England[9]

the robustness of the entire building to an accidental event. A vertical extension will increase the consequence of damage, especially for residential buildings with multiple occupants. Robustness may not have been considered in the original design and there is limited guidance about how to improve the resistance of traditional forms of construction.

Within the UK, the requirement to consider disproportionate collapse was introduced to the Building Regulations in 1970 following the collapse of the Ronan Point tower[8]. Approximately half of existing blocks of flats were therefore built without robustness in mind **(Figure 2)**. However, even for those built after 1970, the extended building may have additional requirements due to the increase in consequence. For example, moving from four to five storeys will result in a change in Consequence Class from 2a to 2b, with the requirement for vertical ties in addition to horizontal ties[10]. If the existing building cannot be shown to be sufficiently robust, extensive strengthening will often be required.

Further guidance on possible approaches with different construction types is provided in guidance documents from the IStructE[11] and Department for Communities and Local Government[12]. However, it should be noted that compliance requires agreement with the approving authorities (e.g. the Building Control Officer in England and Wales), so early consultation is recommended.

Fire resistance

The fire performance of the entire building must also be justified. Increasing the occupancy and height of the building increases both the likelihood and consequence of fire, e.g. due to longer evacuation times and more challenging firefighting operations. As a result, the fire strategy for the extended building may require increased structural fire resistance. The appraisal of the existing structure must also consider known shortcomings in the original codes, e.g. cover requirements in slabs[13]. Passive remediation measures may be needed (e.g. boarding, cementitious spray or intumescent paint). Alternatively, performance-based structural fire engineering methods could be explored.

Within the UK, the Building Safety Bill (currently being discussed in parliament) will require any latent safety concerns to be identified and mitigated for all buildings, regardless of any proposed modifications. This may also require fire safety improvements relating to means of escape, combustible cladding, compartmentation, smoke control, sprinklers and firefighting access.

Non-structural considerations

The focus of this article is the appraisal and retrofit of the structure for vertical extension, but consideration of the challenges and opportunities for other disciplines can lead to integrated design solutions that provide broader sustainable outcomes. For example, the inclusion of elevators within the development will improve the accessibility of the building and the upgrade to existing elevators could improve the fire safety strategy. For many years, the UK government has been supporting retrofit programmes to upgrade the energy performance of the existing housing stock and further funding was announced in 2020. These programmes should be coordinated and used as a stimulus to deliver on broader retrofit needs.

Case study

This case study aims to put the considerations discussed in this article into context and illustrate possible design solutions based on the capacity and condition of the existing building. Although it is tempting to assume that the best case can be achieved, as with all refurbishment projects, the actual situation may not be confirmed until the contractor is on site. This uncertainty should be explained to the client and opportunities for integrated solutions explored. The embodied carbon for each scenario has been estimated and compared to demonstrate the carbon impact.

Typical constraints

The hypothetical example is based on a two-storey extension to a four-storey purpose-built block of flats, as targeted by the new permitted development rights in England. The existing building is typical of those constructed in the 1960s and consists of reinforced concrete slabs on loadbearing masonry walls with shallow foundations. No records are

↘FIGURE 3: Case study building

available, so intrusive investigations should be expected to confirm the structural details. The flats will remain occupied, so disruption due to investigations, strengthening works and construction of the extension should be minimised. An example of such a building is shown in **Figure 3** and its representation within England shown in **Fig. 2**.

Potential scenarios

Four scenarios have been considered based on the capacity and condition of the existing structure and its foundations for the increase in demand **(Table 1)**. The options which retain the existing building vary from Scenario 1, where the extension can be installed on top of the existing building, to Scenario 3, where an independent 'exoskeleton' on new foundations is constructed around the existing building to support the extension.

Scenario 2 represents an intermediate situation involving strengthening works, but this has not been considered further as it will depend on the specific details of the building and would cause significant disruption to the occupants. Scenario 4 represents demolition of the existing building and construction of a new six-storey building.

Concept-level designs for each scenario have been developed to estimate the embodied carbon of the development. In Scenarios 1–3, light-gauge steelwork has been used for the extension structure. This provides a lightweight solution that minimises the demand on the existing structure and can be fabricated off site to minimise disruption to the occupants. Alternative solutions could include cross-laminated timber platform construction.

A composite deck has been included to provide the transfer between the extension and existing structure. This can resolve vertical and horizontal load paths and may improve robustness.

In Scenario 3, the exoskeleton and stability bracing have been provided with steelwork that can be erected around the existing building.

A particular solution for Scenario 4 has not been developed, but the range of embodied carbon is based on the 2020 and 2030 targets for residential buildings outlined by the London Energy Transformation Initiative[14].

These assumptions represent viable solutions in the current market but it is expected that detailed assessment of alternative systems could result in lower values.

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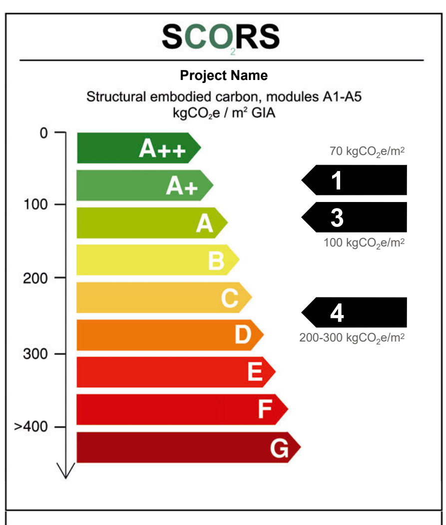

↑FIGURE 4: Structural embodied carbon comparison

Carbon impact

The structural embodied carbon of the different scenarios is shown on the SCORS rating scheme[15] in **Figure 4**. The difference between Scenario 1 and 3 indicates that a structural solution that does not rely on the existing building involves almost 50% more embodied carbon than one that can justify the increase in load on the existing structure and foundations.

Providing an exoskeleton and new foundations may appear extreme, but it is still a lower-carbon option than demolishing and constructing a new building on the same site, as demonstrated by Scenario 4. There may also be opportunities to integrate the exoskeleton with new cladding or lift cores.

It is possible that providing the same amount of housing in a different location may require less embodied carbon, especially as the structural options available will be less constrained. However, this may not be within the influence of the structural engineer and may not deliver on broader sustainability goals, as described above.

It is important to note that the whole-life carbon of the development has not been assessed and the potential to minimise operational carbon must also be considered for each scenario.

Commentary

As structural engineers, we can contribute most directly to sustainability through the quantity and intensity of the materials we specify. We will often be asked to compromise on the embodied carbon of our designs, but perhaps this should only be accepted if this allows the project to contribute to sustainability in other ways. In this situation, the UN Sustainable Development Goals can provide a useful framework for agreeing the right compromises.

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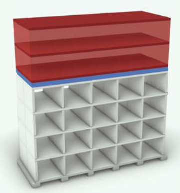
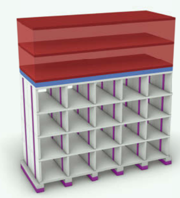
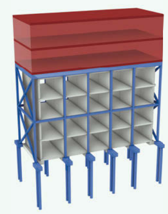
TABLE 1: Scenarios 1–4 for case study building

Scenario	1	2	3	4
				
Investigations	Acceptable condition and capacity confirmed	Insufficient condition and capacity for extension	Intrusive investigations avoided	N/A
Modifications	Limited modifications required	Strengthening to foundations and/or existing structure	Limited modifications required	Demolition
New construction	Lightweight extension and transfer deck	Lightweight extension and transfer deck	Extension independently supported on exoskeleton and new foundations	Six-storey building
Structural embodied carbon A1–A5* [$kgCO_2e/m^2$]	70	70–100	100	200–300

* The embodied carbon estimates have been calculated based on the floor area of the entire building

Key to diagram
☐ Existing structure
■ Transfer structure
■ Superstructure
■ Strengthening of existing structure

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